Space Weather Technical Forecast

Issued on Tuesday, 26 December 2023 at 12:58 Local

This technical forecast provides a four-day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

Space Weather Forecast Headline: Risk of G1 or perhaps peak G2 from midweek UTC from series of CMEs. Now-reduced Chance of further R1s.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Solar activity, as measured by GOES16, has been Low over the past 24 hours, with only minor C-class flares observed. The largest of these events was a C4.5 at 26/0501UTC, originating from narrowly ahead of the visible leading spot of AR3529 in the southwest quadrant - this has been and remains the main source of front-side activity through the Christmas period.

There are currently eight sunspot regions on the visible disc, one of which is a new and currently unnumbered sunspot region emerging in the southeast quadrant, although this appears to be small and stable at present. The main change in the period was the emergence of minor spots surrounding AR3531 near the solar meridian and its developing bipolarity, with other regions apparently stable or in decay.

In a very different vein to the previous 24 hours, no new Earth-directed Coronal Mass Ejections (CMEs) were seen in imagery, although numerous potential sources remain in the form of many filaments.

Solar Wind / Geomagnetic Activity: Solar winds, as measured by ACE and DSCOVR at L1, were Slightly Elevated throughout the period. The reason for this remains uncertain, but is perhaps a marginal and weak positive polarity fast wind, with an uncertain source.

The solar wind speed rose gradually over the 24 hours, rising from around 450 to 475km/s. The solar wind density fell slightly from low double figures ppcc to more typical single figures into the current UTC day. The IMF was slightly variable in magnitude below 8nT, while the north-south component showed a changeable character between limits of +/-7nT. The phi angle was variable at first, but settled on mostly positive (away from the Sun) after 25/1800UTC.

The net result of the above solar wind measures was for provisionally Quiet geomagnetic activity throughout the period.

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux was very slightly raised above resting Background levels in the 24 hours, although below S1 (10pfu) and in fact even below 1pfu for the duration.

GOES16 high energy (greater than 2MeV) electron flux was mostly at Normal Background levels. The 24-hour fluence was below Active throughout and declining, with the 26/0001UTC observation being 3.11e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Low to Moderate activity is forecast, with a now slightly reduced chance of isolated

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M-class X-ray flares.

Solar Wind / Geomagnetic Activity: There has been a glut of CMEs over the Christmas period, with the distilled result being of two possible glancing blows and one more assured hit. These events are likely to interact and as such there is lower than average confidence in the geomagnetic forecast, even though no coronal hole fast winds feature.

Geomagnetic activity will be most reliably Quiet in the current UTC day. A pair of CME glancing blows are then expected on 27 and 28 December, with a third more direct hit also possible on 28 December. The possibility that this final CME arrives concurrently with the second glancing blow should give rise to a peak risk of G1, and perhaps even G2 in the UTC day of 28 December, with a residual tail of effects perhaps continuing into 29 December.

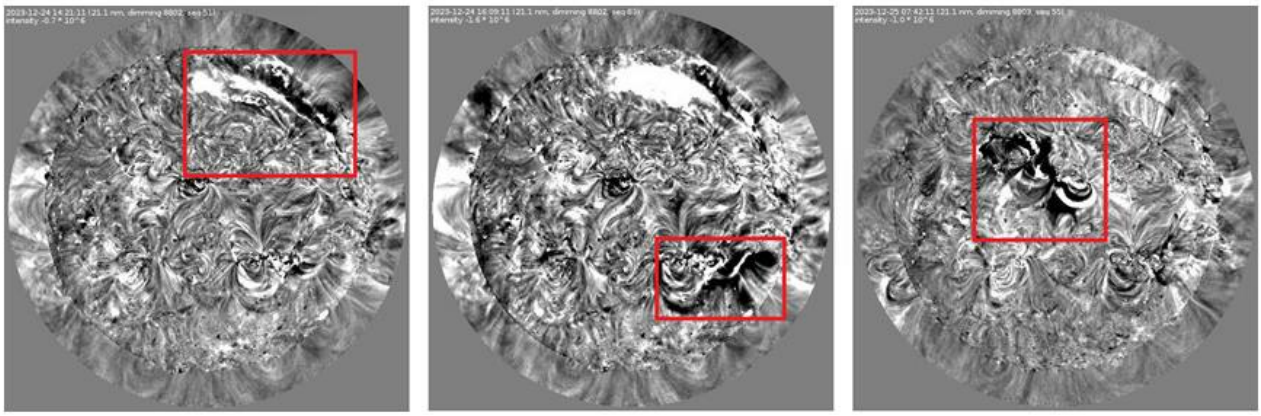

Figure 0: Time-integrated AIA211 imagery processed by SIDC ROB showing the three sources of CMEs due in the forecast period.

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is near Background and likely to persist at this level, but with a Slight Chance of increasing given any further notable flares from AR3529 or other regions on the disc.

GOES16 high energy electron flux is expected to persist at mainly Normal Background levels, with the associated fluence remaining below the Active level throughout.

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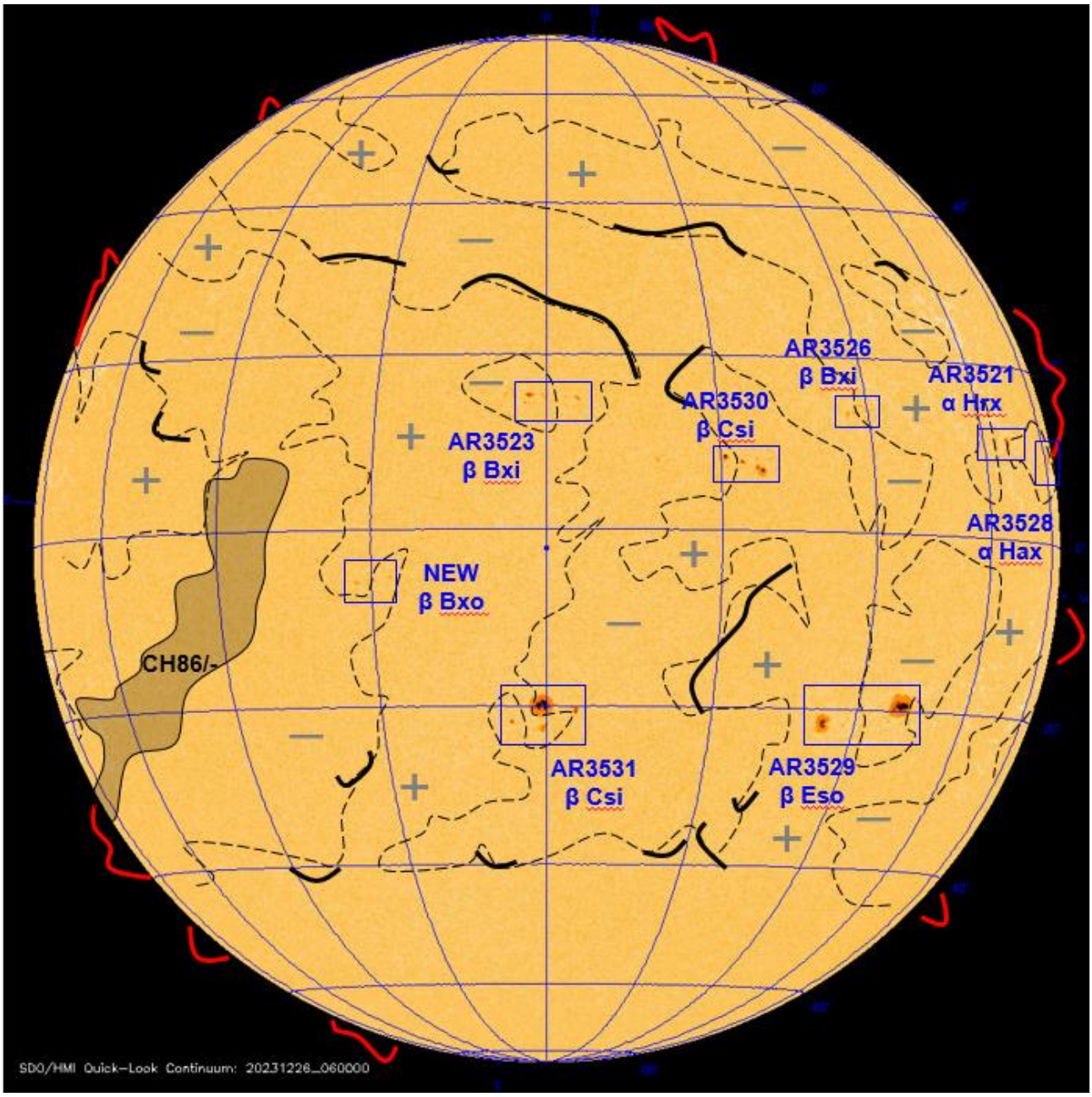
Figure 1. Solar Analysis Valid 26/0600UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

No coronal hole fast winds feature in the forecast - the current unforecast enhancement has long-peaked (at Kp3 on 24 December) in potency and should soon abate.

A great number of CMEs were observed over the Christmas period, however three have stood out as being of potentially more relevance. Overall, the forecast carries high uncertainty given the marginal effects from two of these three CMEs, but also due to their probable inter-connectivity, with each possibly priming the interplanetary medium for the next. The most noteworthy events are summarised as:

Firstly, a large filament eruption from the northwest disc around 24/1200UTC. This may give a glancing blow from around the middle of the UTC day of 27 December, but is aimed mainly above and ahead of the Sun-Earth line.

Secondly, a coronal dimming from the southwest disc, around 24/1430UTC. This may deliver a second glancing blow around UTC dawn on 28 December. This CME is angled mainly below and ahead of the Sun-Earth line.

Thirdly, and most directly, a coronal dimming that occurred just northeast of centre-disc around 25/0700UTC. This presented on coronagraph imagery as a halo with a slight eastward bias. This will likely affect Earth, however the main uncertainty here is the arrival time - given the poor triangulation offered by STEREO and Lasco viewpoints at this stage of the cycle, but also because the earlier glancing CMEs may impede or sweep clear the interplanetary medium ahead of this following halo.

MOSWOC Enlil has come close at times to modelling these three CMEs as a very large united density front, but more frequently has kept them as closely-spaced separate events. The model itself appears to have a reasonable treatment of current winds and forecast ambient conditions of fast winds, which increases confidence in CME transit times to 1AU, assuming the analyses were reasonably accurate.

Geomagnetic activity will be most reliably Quiet in the current UTC day. 27/1200UTC and 28/0600UTC are then the most likely times for the glancing blows to pass 1AU, giving a Chance of G1 in themselves. It is possible that Earth could 'thread the needle' and see both of these events pass to no effect, however the third CME appears unavoidable, with a most likely arrival time of 28/1400UTC, but with very large error bars (perhaps +/-12 hours). Although weak in itself, this third CME may therefore arrive in close proximity to one of the glancing blows, which will in any case lead to the peak risk of geomagnetic activity in the period, and perhaps even a Moderate Storm G2, although G1 is much more Likely. A tail of risk then extends into the final day of the four on 29 December.

Geo-Magnetic Storm	**Level**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability (Exceedance)			**(%)**	**(%)**	**(%)**	**(%)**
Minor or Moderate	**G1 to G2**	No	1	40	60	20
Strong	**G3**	No	1	1	5	1
Severe	**G4**	No	1	1	1	1

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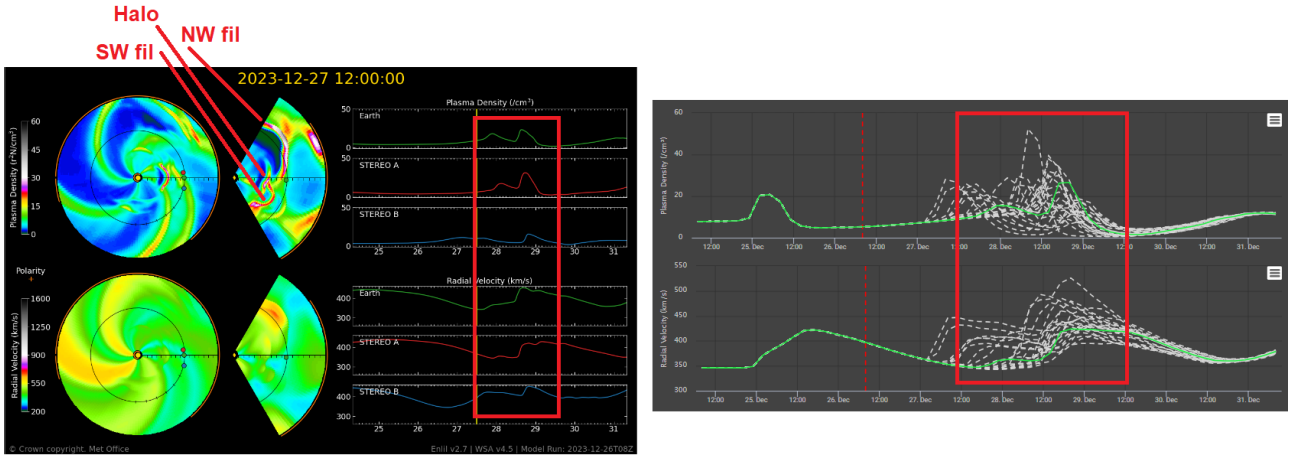
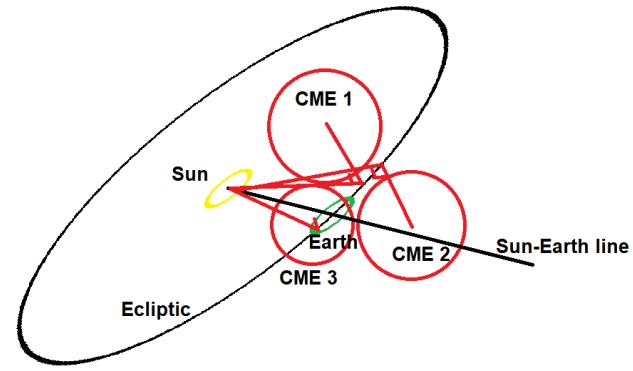
Extreme	**G5**	No	1	1	1	1

Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
24/1732	Partial?	Filament	NW	850km/s	27/1200UTC +/-12 hours	Low confidence, glancing blow
24/2224	Partial?	Filament	SW	572km/s	28/0600UTC +/-12 hours	Low confidence, glancing blow
25/0700	Full	Filament	NE centre	538km/s	28/1400UTC +/-12 hours	High confidence hit, low confidence timing and interaction with other CMEs

Figure 2: Latest MOSWOC Enlil and ensemble (badge time 26/0800UTC) showing three closely-spaced but distinct CMEs crossing 1AU on and after 27/1200UTC, best viewed in side-on conic section. The main risk period is then the boxed red section from 27/1200UTC into early 29 December. Also shown below is an approximate representation of the inbound CMEs.





Radio Blackouts - X-Ray Flares:

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Met Office Space Weather Technical Forecast

Low to Moderate activity is forecast, with a now-reduced daily Chance of isolated M-class flares. After a more active pulse through the Christmas period due in large part to developments in AR3529 in the southwest, the X-ray trace has settled near the B/C flux boundary, with occasional mid-ranking C-class activity. The sunspots on the facing side show relatively little complexity at present and are either stable and mature, or else slowly fading. The one exception to this is AR3531, which saw some minor spots develop in the ambit of the main penumbral group to give bipolarity, although this has not been accompanied by flares.

An M-class flare was observed over the southeast limb on 24 December, and it remains to be seen if this is the precursor to a more active region rotating onto the disc. Along with a distinct area of magnetic looping visible on AIA171 in the northeast, this may suggest the potential for further arriving regions, although these will be assessed when they present for analysis.

Overall, a now lower daily Chance of M-class flares is suggested, with the most significant sunspot group - AR3529 - present throughout the four days.

X Ray Flares	**Level**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability			**(%)**	**(%)**	**(%)**	**(%)**
Active	**R1-R2 M Class**	No	25	25	25	25
Very Active	**R3 to R5 X Class**	No	1	1	1	1

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Solar Radiation Storms - (High Energy Protons):

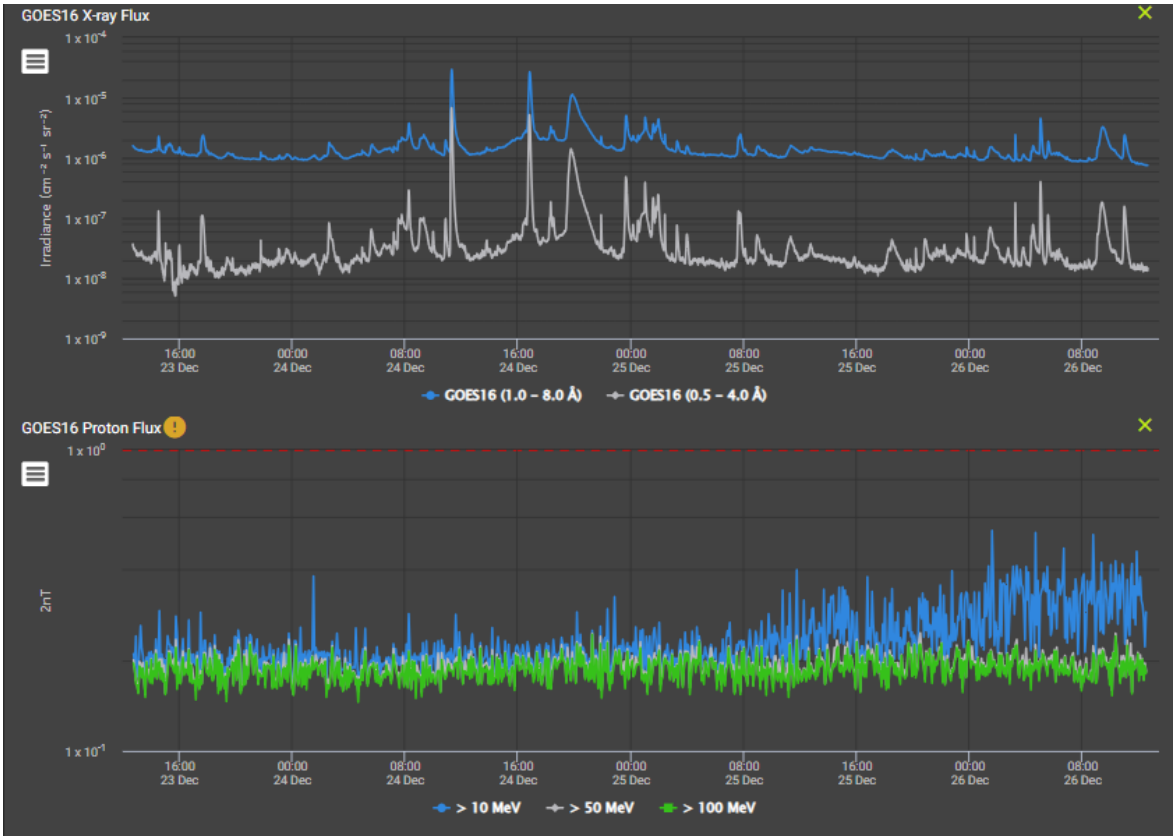
GOES16 high energy (greater than 10MeV) proton flux was very slightly raised above resting Background levels in the 24 hours, although below S1 (10pfu) and in fact even below 1pfu for the duration. The cause of this enhancement is not known, however given the very gradual rise and soft spectrum, it may be a far side or even eastern limb event, perhaps even the long-period M1.1 from behind the eastern horizon on 24 December.

There is a daily Slight Chance of proton enhancement if any further M-class flare activity were to occur from AR3529, and after this there remains a regular supply of more minor spots moving into favourable locations, giving a small but overall constant daily risk.

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	≥ S1	No	5	5	5	5
Very Active	≥ S3 *	No	1	1	1	1

* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)

Figure 3: Past three days in GOES16 X-ray flux and high energy protons, showing a delayed and damped response to any of the frontside M-class activity (if, indeed, even the source)



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High Energy Electrons Event (≥ 2MeV):

High energy electron flux (greater than 2MeV) observed by GOES16 is mostly at Normal Background, with no further coronal hole influences featured in the forecast, although brief periods of Moderate flux are likely. There are then the CME glancing impacts possible from 27 to 29 December, and these are likely to further suppress observed flux at GEO until after this four-day period.

The associated 24-hour fluence is expected to persist below Active (1e8 pfu) as a result of the above. Regarding MOSWOC REFM, the fact that the current possible fast wind enhancement is not forecast nor a persistent feature, as well as the presence of three possible CMEs later in the period, will mean that although the initial trend is accepted, the rational is probably incorrect. MOSWOC REFM should not be followed in the second half of the period, although the forecast low fluence count is probably correct.

GEO Electron Environment	**Level (cm^{-2} sr^{-1} day^{-1})**	**Past 24 Hours (Yes/No)**	**Day 1 (00-24 UTC)**	**Day 2 (00-24 UTC)**	**Day 3 (00-24 UTC)**	**Day 4 (00-24 UTC)**
Probability (Exceedance)			**(%)**	**(%)**	**(%)**	**(%)**
Active	**≥ 2 MeV ≥ $1x10^8$**	No	1	1	1	5
Very Active	**≥ 2 MeV ≥ $1x10^9$**	No	1	1	1	1

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